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Fast Acting Optical Beam Deflection System

First and Second Interim Report

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1. Introduction

The primary objective of the present investigation is to seek an effective and practical method to detect and suitably deflect a coherent optical radiation from its initial direction of incidence and thus avoid the occurrence of serious biological damages which may be caused by such harmful radiations in the wavelength range of 0.4 - 1μm.

In the research proposal a possible effective method of simultaneous detection and deflection method using a blazed diffraction grating has been discussed. This report provides a brief summary of the progress which has been made since the present contract was granted on 24th May 1988.

The first periodic report was due in June 1988. However, there was very little to report at that time as we did not receive two experimental gratings from the Cambridge Consultants until early August 1988. The European Researcch Office of the U.S. army was, of course, well aware of the situation as the relevant contract for the suitable transmission grating was placed directly by the E.R.O. office to the Cambridge Consultant. In view of the above, it is felt appropriate that the expected first and the second report may be usefully submitted as a joint report.

2. Theory of Transmission Grating

A diffraction grating is an optical surface with many straight, parallel and equally spaced grooves which provide an optical diffraction due to the mutual interference of the light beams. A transmission grating can be used in both the visible and ultraviolet regions of the optical spectrum. Modern technology allows to fabricate gratings which transmit well down to 2000 A^0 using clear quartz as the grating material.

The distribution of light into various orders of a grating depends upon the microscopic shape of the grooves of the grating. By ruling the grating with and controlling the angles of the grooves it is possible to concentrate the spectral energy in any desired angular region. This is called "BLAZING" a grating, and the groove-face angle ϕ is called the blaze angle (figure 1).

For a transmission grating, the grooves may be formed either in transparent resin that is strongly adherent for the surface of a substrate glass or directly on the glass itself. This latter case is desirable for our purpose as the resin may suffer aging by the incident coherent radiations. The blaze angle ϕ, is calculated so that the light of the blazed wavelength λ_B, will be refracted at the constructive interference angle for that wavelength.

In the simplest case, the light is incident normal to the unruled plane surface of the transmission grating and leaves the grating at the angle of diffraction β (figure 1) from the ruled surface. For this condition, the diffraction grating equation becomes

$$\mathrm{Sin}\beta = \lambda_B / d \qquad (1)$$

where λ_B is the optical blaze wavelength of the incident radiation and d the grating spacing (pitch) in the same units as the wavelength. From Snell's law we have

$$n_g \,\mathrm{Sin}\,\phi = \mathrm{Sin}\,(\phi + \beta) \qquad (2)$$

where N_g is the refractive index of the diffracting material, i.e. glass in our case. Combining equations 1 and 2, the following expression for the blaze (groove) angle ϕ, may be obtained for the grating for a given blaze wavelength λ_B.

$$\phi = \tan^{-1}\left[\frac{\lambda_B}{n_g d - (d^2 - \lambda_B{}^2)^{1/2}}\right] \qquad (3)$$

3. Specifications of the two identical Replica Gratings provided by the Cambridge Consultants

(i) Substrate: Shotglass type BK7 (refractive index = 1.51509)
Grating Material: Epoxy with refractive index = 1.59 at a wavelength of 0.633μm.
Diameter: 5 cm
Thickness: 1 cm
Blaze angle: 31.6^0
600 lines/mm

4. Results & Discussion

We have $d = \left[\frac{1 \times 10^{-3}}{600}\right] m = 1.667 \times 10^{-6} m$
For $\lambda_B = 0.633 \times 10^{-6} m$ (He - Ne laser)
$n = 1.59$ and using equation 3, we get $\phi = 29.71^0$ as compared with the manufacturer's specification of 31.6^0.
Using the stated d- value and equation 1 the magnitude of the first order diffraction angle is 22.32^0.

Thus for the present grating at $\lambda = 0.633 \times 10^{-6}$ m and with $d = 1.667 \times 10^{-6}$ m. We have Blaze angle, $\phi = 29.71^0$ and first order diffraction angle, $\beta = 22.32^0$.

Now, combining equations 1 and 2 the blaze wavelength λ_B is given by

$$\lambda_B = d \operatorname{Sin}\left[\operatorname{Sin}^{-1}(n_g \sin \phi) - \phi\right] \quad (4)$$

Using the given values of d and n_g i.e. 1.667×10^{-6}m and 1.59 respectively, and the calculated value of ϕ i.e. 29.71^0, we get from equation 4

$$\lambda_B = 0.6323 \times 10^{-6} m$$

which is indeed in good agreement with the λ (He - Ne) value (i.e. 0.633×10^{-6}).

Such a grating should be effective for the wavelength range

$\frac{2\lambda_B}{3}$ to $2\lambda_B$ to deflect 80% of coherent light in the range

0.422 $\times 10^{-6}$m to 1.265 $\times 10^{-6}$m (i.e. 422 nm to 1265 nm).

A photo-detector assembly has been fabricated in our laboratory using three photo diodes with which the two outer photo-diodes can be moved synchronously with respect to the centre photo-diode by a stepping motor assembly. The two outer photo-diodes can also be individually rotated about a vertical axis to receive the diffracted light (first order) at a normal angle of incidence to the photo-diode sensor. The central photo-diode has been provided with a small manual adjustment facility to receive the zeroth order (undiffracted) beam at a normal angle of incidence. Using this equipment the diffraction behaviour of the two replica gratings have been studied and figure 2 shows the results from which it may be noticed that with the gratings in situ, (He-Ne laser, $\lambda = 0.633 \times 10^{-6}$m) the ratio of the peak amplitudes of the first order and zeroth order beams is approximately 7:1 which is in agreement with the expected grating efficiency. However these figures should be treated with caution as accurate and detailed measurements, in this aspect are stil in progress.

A prism spectrometer is being set up to obtain information on the diffraction behaviour of the present grating over a band of frequencies using white light as the primary source of illuminations.

The author was given 11 replica gratings with different d-spacings and blaze angles. These gratings will be analysed in course of this programme,

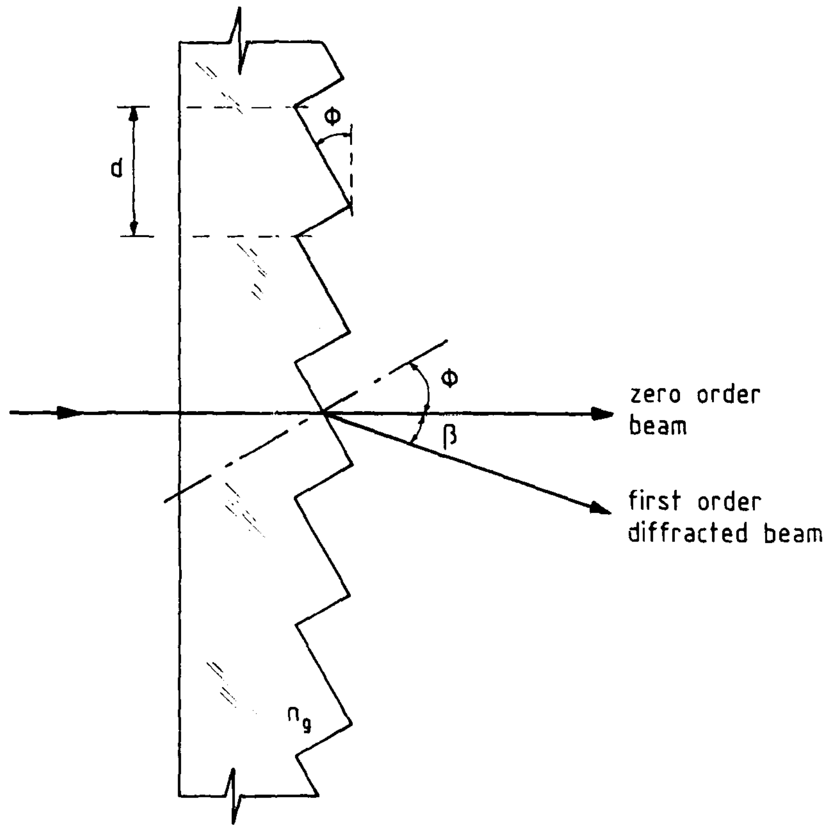

Figure 1. Blazed transmission diffraction grating.

Figure 2. Intensity profile with grating.

$\lambda = 0.6328 \times 10^{-6}$ m (He-Ne laser)

$\beta = 23°$